E7.5-10.3.2.1

CR-142923

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Computer Mapping of Turbidity and Circulation Patterns in Saginaw Bay, Michigan from LANDSAT Data		5. Report Date March 1975 6. Performing Organization Code
7. Author(s) R.H. Rogers, L.E. Reed, V. Elliot Smith		8. Performing Organization Report No. BSR 4183
9. Performing Organization Name and Address Bendix Aerospace Systems Div. 3621 South State Rd Ann Arbor, Mich. 48107		10. Work Unit No. 11. Contract or Grant No. NAS 5-20942
12. Sponsoring Agency Name and Address Goddard Space Flight Center Greenbelt, Md. 20771		13. Type of Report and Period Covered Special Report 14. Sponsoring Agency Code

15. Supplementary Notes

Published in Proceeding of the American Society of Photogrammetry 41st Annual Meeting; Washington, D.C.; March 1975.

16. Abstract

LANDSAT CCTs were used as a basis for producing geometrically-corrected color-coded imagery of turbidity and circulation patterns in Saginaw Bay, Michigan (Lake Huron). This imagery shows nine discrete categories of turbidity, as indicated by nine Secchi depths between 0.3 and 3.3 meters. The categorized imagery provided an economical basis for extrapolating water quality parameters from point samples to unsampled areas. Furthermore, LANDSAT furnishes a synoptic view of water mass boundaries that no amount of ground sampling or monitoring can provide.

(E75-10321) COMPUTER MAPPING OF TURBIDITY AND CIRCULATION PATTERNS IN SAGINAW BAY, MICHIGAN FROM LANDSAT DATA (Bendix Corp.) 16 p HC $3.25 CSCL 08H

N75-26465

Unclas

G3/43 00321

17. Key Words (Selected by Author(s))	18. Distribution Statement
Water Quality, Computer Mapping, ERTS, LANDSAT	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*

Original photography may be purchased from:
EROS Data Center
10th and Dakota Avenue
Sioux Falls, SD 57198

COMPUTER MAPPING OF TURBIDITY AND CIRCULATION PATTERNS IN SAGINAW BAY, MICHIGAN (LAKE HURON) FROM ERTS DATA

Robert H. Rogers and Larry E. Reed
Bendix Aerospace Systems Division
Ann Arbor, Michigan 48107

V. Elliott Smith
Cranbrook Institute of Science
Bloomfield Hills, Michigan 48013

BIOGRAPHICAL SKETCHES

Dr. Robert H. Rogers is a senior staff engineer at Bendix, where he is a Principal Investigator for NASA/ERTS and Skylab/EREP programs. Rogers received his BS from Tri-State College, his MS from Southern Methodist University, and his PhD in EE from Michigan State University. He is a member of the ASP, and has published many papers in the field of Remote Sensing. Dr. V. Elliott Smith is Coordinator of Lake Research at Cranbrook Institute of Science, where he is the Principal Investigator for an EPA-funded survey of water chemistry in Saginaw Bay (Lake Huron). Smith received his BS and MS degrees in Biology from Florida State University and his PhD in Marine Biology from Scripps Institution of Oceanography. He has published several papers in the fields of biochemistry, biology, and remote sensing. Larry E. Reed is a projects investigator for Bendix and is actively involved in the processing and analysis of data from ERTS, Skylab, and Bendix multispectral scanners. He has seven years of experience as an Air Force image interpreter, using aerial photography, side-looking radar, and infrared imagery.

ABSTRACT

Computer techniques developed for mapping water quality parameters from ERTS data are demonstrated, using ground truth collected in an ongoing survey of water quality in Saginaw Bay, Michigan (Lake Huron) sponsored by the U.S. Environmental Protection Agency. Chemical and biological data were collected in concert with ERTS passes at 59 bay stations within the 2,960 square kilometer (1,143 square mile) test area. These ground truth measurements include water turbidity and clarity, chlorophyll, algal populations, total and dissolved nutrients, and metals.

A technique for transforming Earth coordinates (latitude and longitude) of bay stations to ERTS tape coordinates (scan line and element number) was developed and applied to edit ERTS measurements near stations representative of a known water quality parameter. These spectral samples were used by the computer to produce geometrically-corrected color-coded imagery and maps of turbidity of the entire bay. These maps show nine discrete categories of turbidity, as indicated by nine Secchi depths between 0.3 and 3.3 meters.

These maps and data, rapidly produced from ERTS data, provide an economical basis for extrapolating water quality parameters from point samples to unsampled areas. Furthermore, ERTS furnishes a synoptic view of water mass boundaries that no amount of ground sampling or monitoring can provide.

BACKGROUND

Recent investigations have studied the feasibility of using ERTS-1 to detect and monitor water quality parameters (Refs. 1, 2, 3, 4)* and the effects of land use on these parameters (Ref. 5). Results of these efforts show that ERTS is capable of detecting subtle changes in water color and reflectivity where the concentration of suspended particles (causing backscatter) is at least a few milligrams per liter. At lower values of turbidity, atmospheric and sensor "noise" interferes substantially. It has also been observed in many ERTS images that the distribution of turbidity within small inland lakes is fairly uniform (Ref. 1), whereas in large lakes and bays it is highly variable (Refs. 2, 3). This investigation recognizes the growing need to map turbidity and color patterns in the Great Lakes, inasmuch as they represent discrete water masses, circulation trends and zones of differing productivity, and water quality. ERTS monitoring, as an adjunct to conventional point-sampling should also provide an economical basis for extrapolating water quality parameters from point samples to unsampled areas and provide a synoptic view of water mass boundaries.

Several institutions and federal agencies in the United States and Canada are conducting a comprehensive survey of water quality and circulation in Lakes Huron and Superior, the Upper Lakes Reference Study, (a part of the United States/Canadian Great Lakes Water Quality Agreement of 1972). One such agency is the U.S. Environmental Protection Agency (EPA). In Saginaw Bay (Lake Huron), EPA is sponsoring a 30-month modeling study of water quality. This bay is heavily enriched by drainage from more than 16,060 square kilometers (6,200 square miles) of urban and agricultural land. EPA's program will develop a deterministic model which will describe water quality changes within the bay and their relationship to enrichment and pollution caused by man. The increasing eutrophication of Saginaw Bay has an impact on both the American and Canadian waters of Lake Huron, Lake Erie, and Lake Ontario. The resulting model will be used to evaluate various strategies to control nutrient flow into the bay. Important goals in this project are to describe, on a seasonal basis, the circulation and water masses in Saginaw Bay, to monitor inputs of nutrients from its watershed, and to develop and evaluate models for predicting water quality in the bay as a function of various control strategies.

---

*References, tables, and illustrations can be found, in that order, at the end of this paper.

Since April of 1974, Saginaw Bay has been monitored by EPA at 59 stations distributed over its 2,265 square kilometer (1, 100 square mile) area. At each station and depth, some 30 parameters are measured in the field or laboratory. While most of these chemical, biological, and physical factors are not directly detectible by any remote sensor, they all influence the productivity and, therefore, the color and reflectance of bay waters.

In response to EPA requirements for large area surveillance of water quality and watershed land use, NASA's ERTS-B investigation (ID 23250) is using the Saginaw Bay area to demonstrate the cost benefits of ERTS for mapping the needed parameters. One goal of this investigation is to determine which water quality parameters can best correlate with ERTS measurements. This paper reports on preliminary results directed toward this ERTS-B goal.

TEST SITE

Saginaw Bay, as shown on the map of Michigan in Figure 1 and in the ERTS image of Figure 2, is a shallow extension of Lake Huron, bounded by five counties of southeastern Michigan. The bay has an area of some 2, 960 square kilometers (1, 143 square miles) and a maximum length and width of 82 kilometers (51 miles) and 42 kilometers (26 miles), respectively. Mean depth of the inner bay is 4. 6 m (15 ft) and of the outer bay, 14. 6 m (48 ft). The Saginaw River enters the bay at its extreme southwestern end. This river and its tributaries drain a watershed of more than 16, 060 square kilometers (6, 200 square miles), which contains four major cities and much agricultural land. Consequently, inputs of salts, nutrients, and pollutants to the bay have been increasing for many years. Levels of turbidity and algal production are consistently high, especially within the inner bay. Major declines in commercial fish yields, wildfowl populations, and aesthetic values have been the result of eutrophication. The natural movement of pollutants from the bay into southern Lake Huron helps to reduce water quality throughout the lower Great Lakes as well. While circulation within the bay is highly wind-dependent, the pattern is generally counterclockwise. Clear Lake Huron water enters mainly along the western shore; turbid bay water exits along the eastern shore. Significant but unknown quantities of sediment are resuspended regularly by wave action. The lower two-thirds of Saginaw Bay usually freezes over during January and February. These and other characteristics of Saginaw Bay are well documented (Ref. 6) by previous studies.

GROUND TRUTH PROGRAM

The EPA measurement program in Saginaw Bay is obtaining a base of information on water quality which will be used to develop and test models of circulation, nutrient loadings, and algal productivity. Since April 1974, surface and subsurface measurements have been obtained at the 59 bay stations shown in Figure 3, on an 18-day interval to coincide with the ERTS overflights.

The first clear ERTS scene of the bay, coincident with surface measurements at the bay stations, was the 3 June 1974 scene noted previously in Figures 1 and 2. The corresponding cruise tracks of the survey vessels obtaining measurements at the bay stations are shown in Figure 3. Typically, as in this 3 June mission, the western half of the bay, containing 31 stations, is sampled on the same day as the ERTS overflight. The remaining 28 stations are sampled on the following two days. ERTS measurements edited near 22 of the bay stations monitored on the day (i.e., coincident with ERTS overflight) were used in the processing reported in this paper.

Field measurements at each of the bay stations include temperature, pH, dissolved oxygen, conductivity, alkalinity, and turbidity. Turbidity is indicated by Secchi depth and percent transmittance measurements. Variables measured in the laboratory include soluble nutrients (nitrate-nitrite, orthophosphate, sulfate, silicate, and ammonia), organic materials (nitrogen, phosphorus, carbon, and chlorophylls), chloride and metals (sodium, potassium, calcium, magnesium, and six trace metals), and total suspended solids. Enumerations of phytoplankton and zooplankton are also made. Coordinated studies of current patterns, nutrient inputs, and bottom fauna are also underway by EPA.

COMPUTER PROCESSING OF ERTS DATA

The need for faster and more economical mapping of water quality and land use has led Bendix into evaluating computer target "spectral recognition" techniques as a basis for automatic target categorization and mapping. These categorization techniques (Refs. 7, 8) have been under continued development at Bendix for the past eight to ten years, primarily using aircraft multispectral scanner data and, more recently, using ERTS/MSS and Skylab/EREP-S192 data.

The elements of the Bendix data center used to process data for this study include Digital Equipment Corporation 1.5-M-word disk packs, two nine-track 800-bit-per-inch tape transports, a line printer, a card reader, and a teletype unit. Other units are a color moving-window computer-refreshed display, a glow-modulator film recorder, and a Bendix Datagrid® System 100 for digitizing graphical data. Figure 4 illustrates the major steps used in transforming the 3 June ERTS CCTs into turbidity maps and data on Saginaw Bay. The steps used and results achieved are briefly summarized in the following paragraphs.

One of the processing steps is to establish the water categories that can be feasibly mapped from ERTS data with an acceptable categorization accuracy. This step requires locating and designating to the computer a number of ERTS picture elements or "pixels" that best represent the water categories of interest, the "training areas". It is these training area measurements that are used by the computer to interpret ERTS measurements over the entire scene.

The first processing goal was to generate a turbidity map of the bay. Hence, the first processing requirement is to locate and extract ERTS measurement (training areas) representative of various degrees of turbidity. At the time of preparation of this paper, the only parameter fully reduced for all bay stations, which is a good indicator of turbidity, is Secchi depth. Percent transmittance was available only for some stations and total suspended solids were not yet measured.

To obtain training measurements representative of various categories of turbidity as measured by Secchi depth, a procedure was developed for transforming the bay station coordinates from latitude and longitude units to ERTS tape scan line and element numbers.

Earth to ERTS Coordinate Transformation

There are three basic steps involved in the automatic referencing of ground coordinates of bay stations to ERTS coordinates. The first step consists of automatic retrieval of the latitude and longitude of carefully selected ground control points from a map through a digitizing process. The criteria for selecting these ground control points is they can be easily and accurately identified on ERTS imagery. The second step consists of converting the latitude and longitude of these ground control points to ERTS coordinates, using a theoretical transformation derived from known and assumed spacecraft parameters such as heading, scan rate, and altitude, and from a knowledge of Earth rotation parameters. The ERTS coordinates and transformation matrices thus obtained are approximate, based on the use of the nominal spacecraft parameters. The approximately-derived ERTS coordinates and transformation are used, however, to identify the actual ERTS coordinates associated with the ground control points. To accomplish this, the coordinates of a ground control point is input to the Bendix data processing system. The approximate transformation computes the ERTS coordinates and displays the area on a TV monitor. Positional error of the ground control points displayed to the operator are designated to the computer by cursor. This error measurement is used by the computer to derive an improved set of coefficients for the transformation matrix. This procedure is repeated on additional ground control points until the desired ge[illegible] achieved. This rapid interactive procedure is essen[illegible]g a transformation matrix which provides an accurate tra[illegible]ion of Earth to ERTS coordinates.

Analysis Phase

When assured that the Earth-to-ERTS coordinate transformation was correct and the bay station areas were being accurately displayed on the TV monitor, the coordinates of training areas about the bay stations representative of nine Secchi depths were designated to the computer. This was accomplished by placing a rectangular cursor over the desired bay station area and assigning a training area designation, category code, and color code. Several bay station areas were picked for each category, as shown by Table 1. The color code was used in

later playback of the tapes when the computer-categorized data was displayed in the designated colors.

The ERTS spectral measurements within the training area boundaries were edited by the computer from the computer-compatible tape (CCT) and were processed to obtain a numerical description representing the "spectral characteristics" (computer processing coefficients) of each water category. One of these numerical descriptors is the average signal in each ERTS band when viewing a water mass of a specified Secchi depth, as shown in Table 1. To test the computer's capability to use these spectral characteristics, they were first applied to categorize data from known bay station areas. The processed results were viewed on the TV monitor and output in the form of accuracy tables.

When satisfaction with the categorization accuracy was achieved on the water categories, the processing coefficients were placed into the computer disk file and used to process that portion of the CCT covering the area. This first step in the categorization processing resulted in new or categorized CCTs, in which each ERTS pixel is represented by a code designating the interpreted water categories. This tape was used to generate geometrically-corrected color-coded images at 1:1,000,000 scale. Enlargements were produced to obtain 1:250,000 scale images. In this categorized imagery, color represents the computer's interpretations, based on the training measurements, as to turbidity as indicated by Secchi depth. The turbidity map of Saginaw Bay, shown in Figure 5, was produced from this color-categorized imagery.

RESULTS AND ANALYSIS

ERTS spectral measurements edited from bay stations of Secchi depth from 0.6 to 3.3 meters show a linear relationship; for depths less than 0.6 meters, a nonlinearity (jump in measurements) is apparent.

To establish categorization accuracy based on Secchi depth, ERTS measurements within a 100-pixel box centered on each bay station was categorized and results were noted and plotted in Figure 6. Secchi depth measurements obtained by boat at the bay stations and measurements categorized by ERTS are noted in the figure. The values are arranged in order of increasing Secchi depth and are grouped by day of measurement. From the data, it is evident that the correspondence of measured and predicted Secchi depths is best on 3 June, the day of ERTS coverage. For a few stations (36, 34, 39, 44, 38, 43), there is a wide discrepancy between measured and predicted Secchi depth, particularly on 4 and 5 June. Notably, all of these stations are located either in areas of partially unclassified water, along boundaries between category-areas, or both. Possible shifts in water masses during the day or two between ERTS passage and Secchi depth measurement could account for this difference.

Conversely, predicted values at stations located well within category-areas are more reliable, even on 4 and 5 June.

There are several factors that could affect the accuracy of Secchi depth predictions from ERTS data. Some of these include:

a. Secchi depth measurement. To some degree, Secchi depth measurement is affected by the observer's eyesight, the time of day, the weather, the state of the sea, and other factors. As turbidity increases, small errors of measurement become more important, particularly for Secchi depths less than 1 m.

b. Variation of reflectance. For reasons of varying particle size and color, surface conditions, sun angle, etc., Secchi depth may not vary linearly with the volume of back-scattered light, as recorded by ERTS.

c. Atmospheric interferences. Non-uniform attenuation of the signal by atmospheric dust, haze, etc. further complicates the relationship between Secchi depth and ERTS measurements.

d. Location of stations by ground crews. Navigational errors can lead to faulty comparison of measured and predicted values, especially for stations located along water mass boundaries. Depending on the location and conditions, the accuracy of ship positioning may vary by several hundred meters.

Study of the turbidity map, Figure 5, produced from the categorized ERTS imagery has confirmed some known features of circulation and water quality in Saginaw Bay. Previous surveys of the bay (Ref. 6) have indicated that the predominant flow of Saginaw River water is northward along the eastern shore of the bay. Less turbid Lake Huron water dominates the outer bay and enters the inner bay chiefly along the western shore. Zones of mixing and local circulation are apparent on the map, as are shoal areas where sediments evidently have been resuspended. Clearly, the image categories mapped from ERTS are related to turbidity levels.

Results of the categorization based on Secchi depth also show that Saginaw River water is a distinct category that is traceable outside the river mouth as it blends with less turbid bay water (forming a new category) and moves up the eastern shore. The Sebewaing River plume is shown as "unclassified" water. Also, good distinction is made between outer and central inner bay water, the latter being more turbid. Finally, the scene categorized from ERTS portrays very distinct boundaries between water masses and little mixing of categories representing widely different turbidities.

CONCLUSIONS

Turbidity maps and data can be rapidly produced from ERTS tapes, using point sampling at the surface in a few select locations. Further work will establish other water quality parameters than can be mapped by ERTS and the number of sampling stations needed.

Only a few water quality parameters; namely, turbidity, chlorophylls, algal populations, and particulate carbon;are expected to have a strong influence on the color or reflectivity of Saginaw Bay water. However, generated maps showing these parameters may provide the tracer needed to map other water quality factors. For instance, highly polluted water from the Saginaw River is characterized not only by its extreme turbidity, but by high chloride and conductivity values as well. Therefore, under some conditions, it should be possible to map chloride content and conductivity along with turbidity. This possibility will also be examined in future work.

REFERENCES

1. R. Rogers and V. Smith, "Utilization of ERTS-1 Data to Monitor and Classify Eutrophication of Inland Lakes," NASA Contract NAS 521810, Final Report, Bendix BSR 4168, November 1974.

2. V. Klemas, M. Otley, W. Philpot, C. Wethe, and R. Rogers, "Correlation of Coastal Water Turbidity and Current Circulation with ERTS-1 and Skylab Imagery," Proceedings of the Ninth International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, April 1974.

3. A. E. Coker, A. Higer, and C. Goodwin, "Detection of Turbidity Dynamics in Tampa Bay, Florida, Using Multispectral Imagery from ERTS-1," NASA Symposium on Significant Results Obtained from the ERTS-1, Washington, D.C., March 1973.

4. J. Scherz, S. Klooster, and J. VanDomelen, "Aerial and Satellite Photography - A Valuable Tool for Water Quality Investigations," Proceedings ASP-ACSM 1973 Fall Convention, Walt Disney World, Orlando, Florida, 2-5 October 1973.

5. R. Rogers, L. Reed, N. Shah, and V. Smith, "Automatic Classification of Eutrophication of Inland Lakes from Spacecraft Data," Proceedings Ninth International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, April 1974.

6. P. L. Freedman, "Saginaw Bay; An Evaluation of Existing and Historical Conditions," EPA Report 905/9-74-003, April 1974.

7. R. Dye, "Multivar... ...tegorical Analysis," Bendix Aerospace Systems Division Special Report BSR 4149, June 1974.

8. R. Dye, P. Hanson, and C. Crawford, "Signature Data Processing Study," Bendix Report BSR 2949, NASA 9-9848, August 1970.

Table 1 ERTS Spectral Measurements from Bay Stations of Known Secchi Depth Used to Generate a Nine-Category Secchi Depth Map of Saginaw Bay.

Bay Stations Used to Obtain ERTS Measurements Representative of Secchi Values	Secchi Depth Bay Stations (Meters)	ERTS Measurements (Average Digital Counts) Edited from Areas of Known Secchi Depth			
		Band 4	Band 5	Band 6	Band 7
1, 9, 54, and 55	0.3	52.5	40.2	27.7	11.4
5 and 7	0.6	43.4	26.7	15.8	3.9
14 and 59	0.8	45.8	28.4	15.7	3.7
2	1.0	47.0	27.2	14.5	3.3
15, 18, and 37	1.3	47.6	26.5	13.4	3.2
20	1.5	45.4	23.5	12.3	2.4
19, 23, 28, 29, and 36	1.7 to 1.8	44.3	23.8	11.9	2.5
31 and 35	2.2	44.4	23.2	12.7	3.2
40 and 45	3.0 to 3.3	42.3	19.7	12.0	3.0

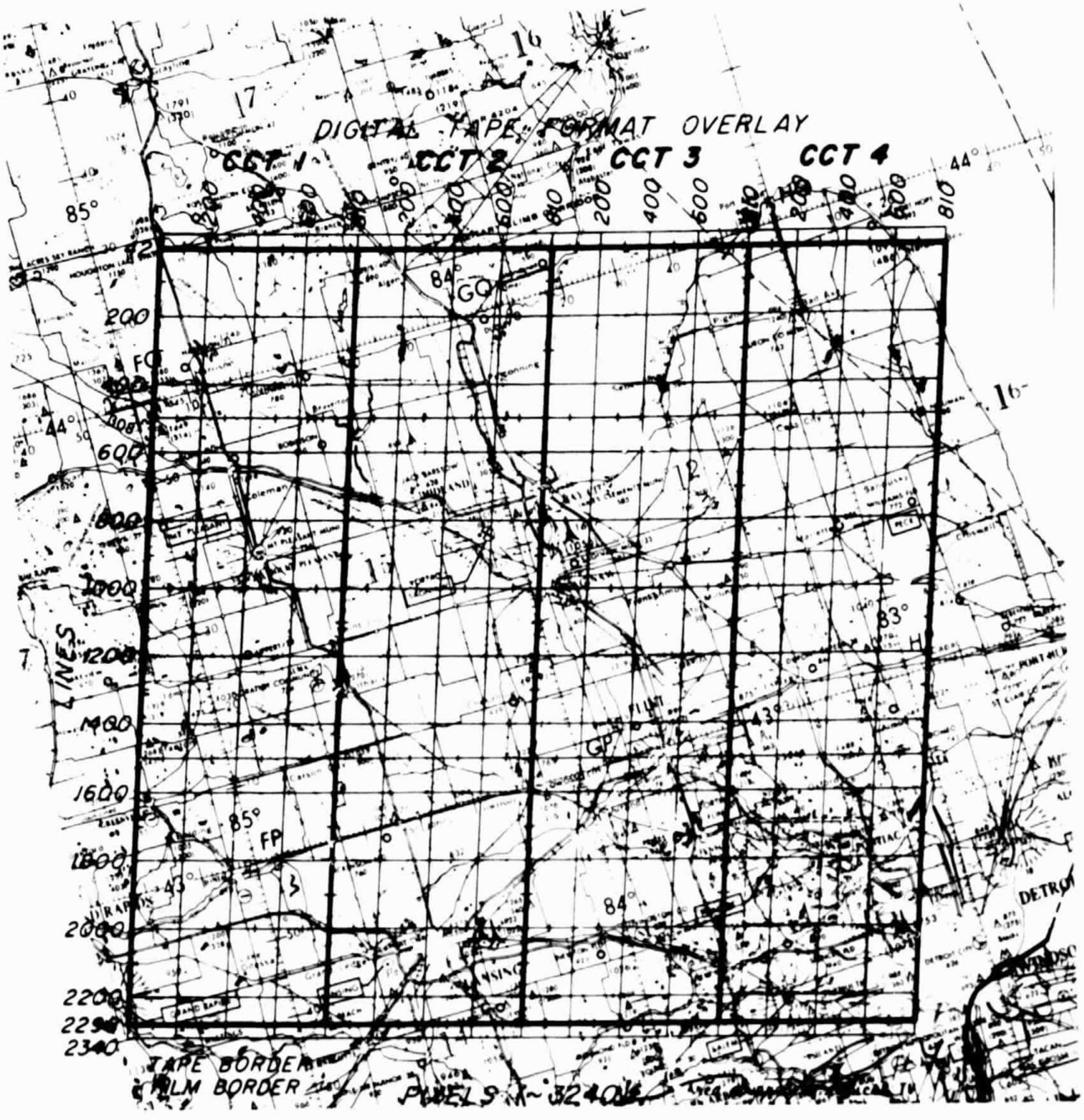

Figure 1 Map of Michigan at 1:1,000,000 Scale Showing Saginaw Bay Test Site and Coverage of ERTS Image Shown in Figure 2. The ERTS coverage diagram illustrates the manner in which ERTS image data is subdivided into four Computer Compatible Tapes (CCTs).

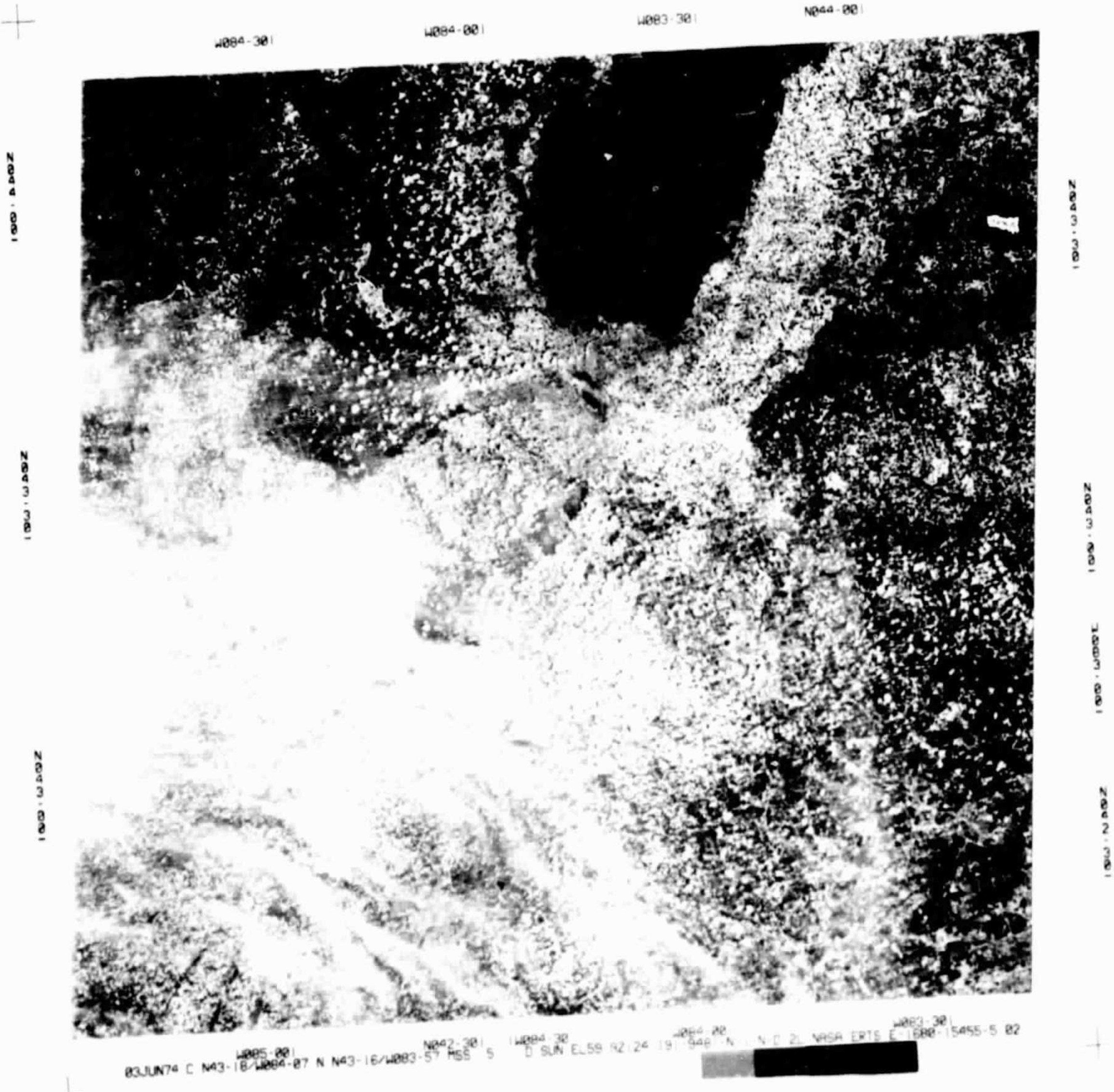

Figure 2 ERTS Image (1680-15455, Band 4) of Lower Saginaw Bay Area for June 3, 1974. Figure 1 shows a 1:1,000,000 scale map of Michigan and area covered by this scene.

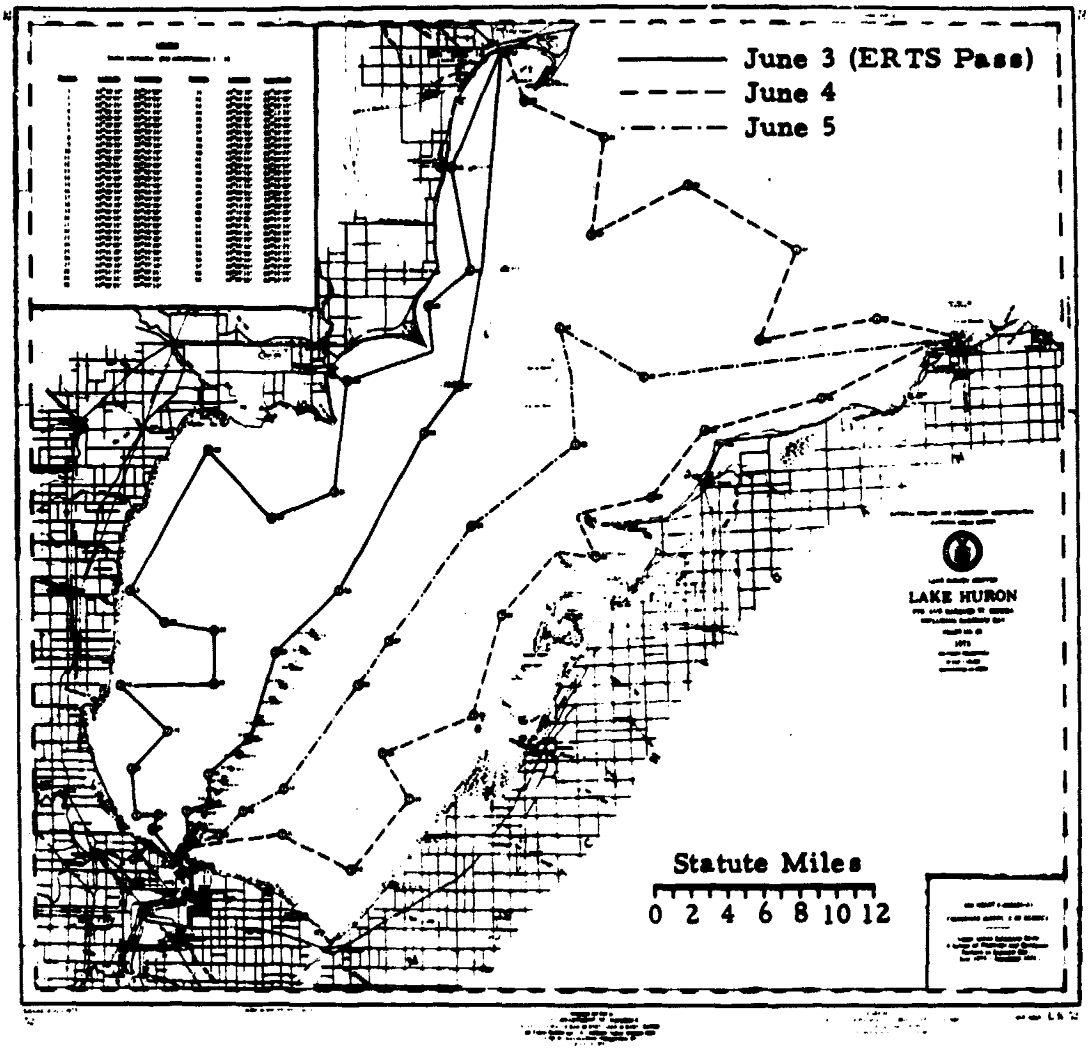

Figure 3 Map of Saginaw Bay with Location of the 59 Bay Stations Denoted by ⊙ , Also Shown are Cruise Tracks of Two Survey Vessels on Saginaw Bay, June 3-5, 1974. Ground truth was collected at 31 stations during a 9 hour period on the day of ERTS passage (June 3).

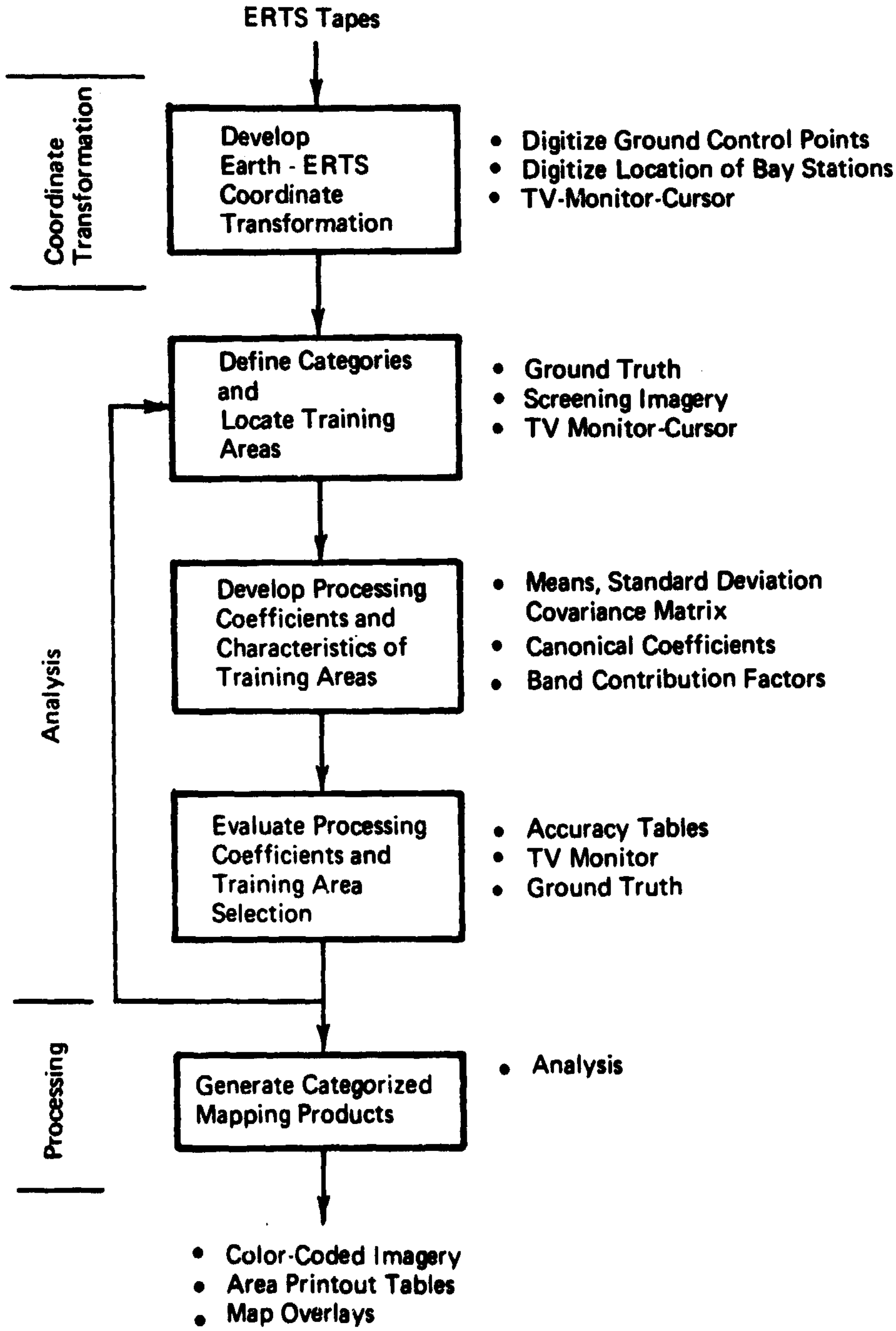

Figure 4 Flow Diagram for Processing and Analysis of ERTS Computer Compatible Tapes

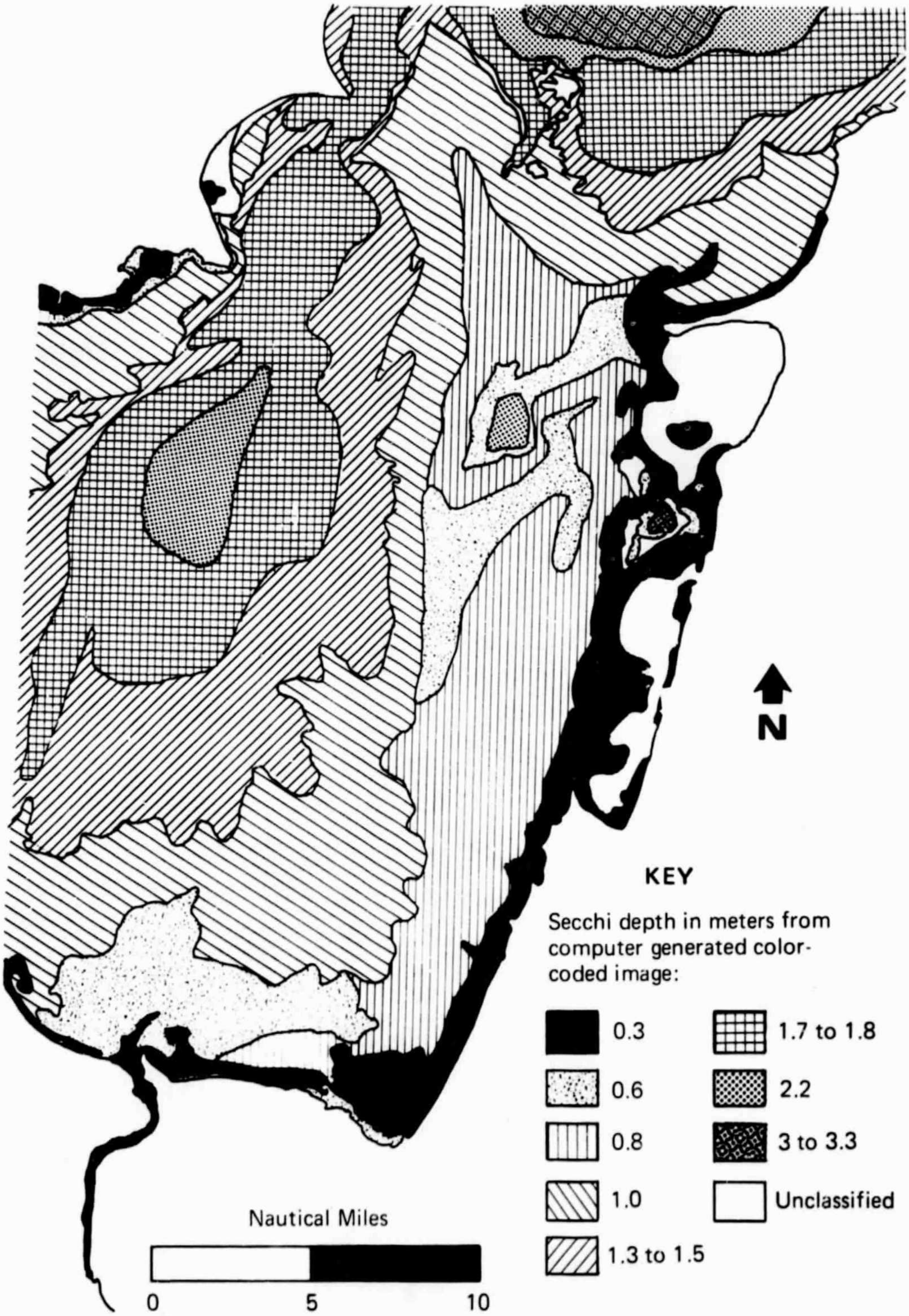

Figure 5 Turbidity Map of Saginaw Bay, Michigan (Lake Huron) Categorized from ERTS Coverage of June 3, 1974.

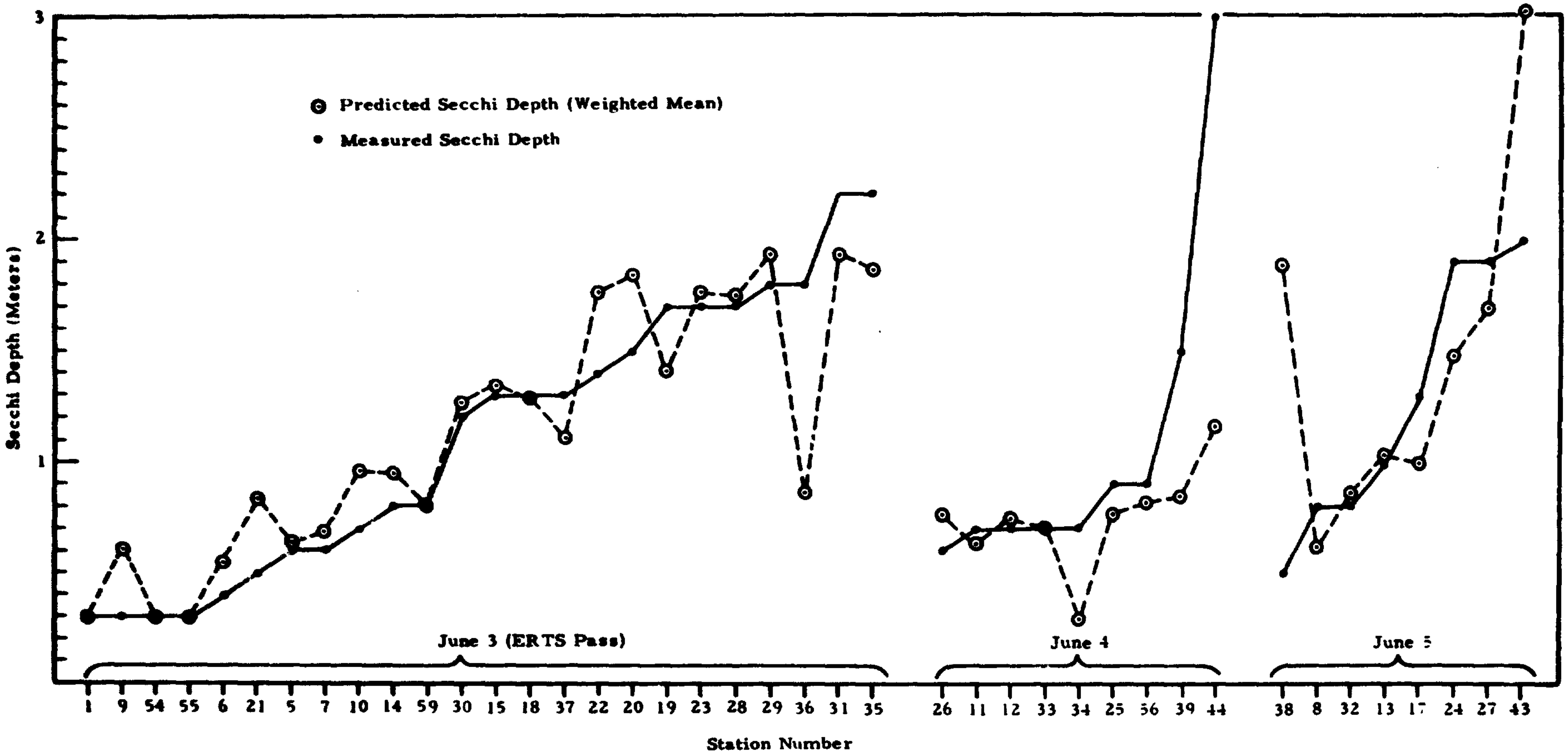

Figure 6 Comparison of Measured and Predicted Secchi Depths.